Input 10 Was metal fatigue a factor?

It would be unlikely if it was not. Several piers collapsed, but not all at the same instant. Their failure was progressive inasmuch that the lugs broke off successively, one pair after another, allowing the tie bars to pull away and consequently throwing the load they had carried on to the adjacent connection. The collapse sequence would have been initiated by the first lug to fracture.

Although the occasion might well have been the stormiest night since the bridge entered service it is hardly likely the forces acting when the train started to cross were double or treble what the bridge had ever been subjected to up to that moment. Yet that would have had to be the condition for an instantaneous failure to occur if there had been on earlier weakening of the critical stressed member(s). On the other hand, if there had been some progressive weakening by a fatigue process the cracked member need only have been awaiting one final application of a load near the top of the normal spectrum to finish it off and trigger the failure of the adjoining members.

Close inspection of enlarged photographs showing the fractured lugs reveals possible evidence of fatigue cracking in at least one pier. This would indicate the attachment of the tie bars had been deteriorating for some time before the bridge finally gave way and it was not simply the stormy conditions on the night of the disaster that were solely responsible.

At the time the Tay Bridge collapsed, fatigue failure was not recognized in brittle materials like cast-iron. In fact, the first laboratory test method to determine fatigue properties was not developed until 1860 by Wöhler, who was investigating failures of steel without the benefit of fractography equipment, such as the scanning electron microscope.

Nevertheless, flake graphite 'grey' cast-irons do suffer fatigue and display an *S-N* characteristic not unlike that of steel. Their fatigue curves flatten off at approximately 35 per cent of their tensile strength after about one million stress cycles. With working stresses higher than 35 per cent of the tensile strength fatigue failures are to be expected in fewer cycles. Cracking will start at a stress concentration point that, in these piers, would be the hole in the lugs through which the tie bars were bolted.

Because cast-iron is brittle and does not exhibit a linear stress-strain curve in the elastic region, the striations that are the characteristic feature of fatigue in ductile metals seldom appear. Instead, the asperities (high spots) of the early developing crack appear slightly flattened in comparison with the last area of the fracture formed as the fatigue crack runs to completion.

Figure C17 shows a bending fatigue fracture of a cast-iron stub axle, where the colour as well as the fracture surface reveals how the fatigue crack started at the bottom and propagated upwards into the section and had reached half way up when the sudden final fracture took place. A second fatigue crack had started at the top shortly before the axle broke but had not grown very far into the section. The brighter, flattened appearance of the fracture near the bottom contrasts with the more sharply defined final area above which exhibits the characteristic grey appearance of sudden fracture of a graphitic cast-iron.

Freshly exposed fractures of cast-iron start to go rusty within an hour or so, especially in salt water. So it is unlikely most of the features shown in this photograph would be evident when the broken castings were examined in the laboratory days after the accident.

Reproductions of the photographs taken during the investigation are not sharp enough for a confident assessment of the lug fractures. However, several, particularly those from piers 3 and 7, exhibit flattening of asperities in areas adjacent to the bolt holes that are consistent with fatigue fractures. These features suggest the critical lugs had been cracking progressively under cyclic loads, probably from the time the first trains ran over the bridge.

The initial cracks would gradually have spread across the section as stress cycles accumulated. Eventually, and inevitably, some lugs would have reached the stage where they were no longer capable of withstanding the loadings applied on that fateful night, despite having most probably withstood similar forces on several earlier occasions before the cracking had spread so far into the sections.

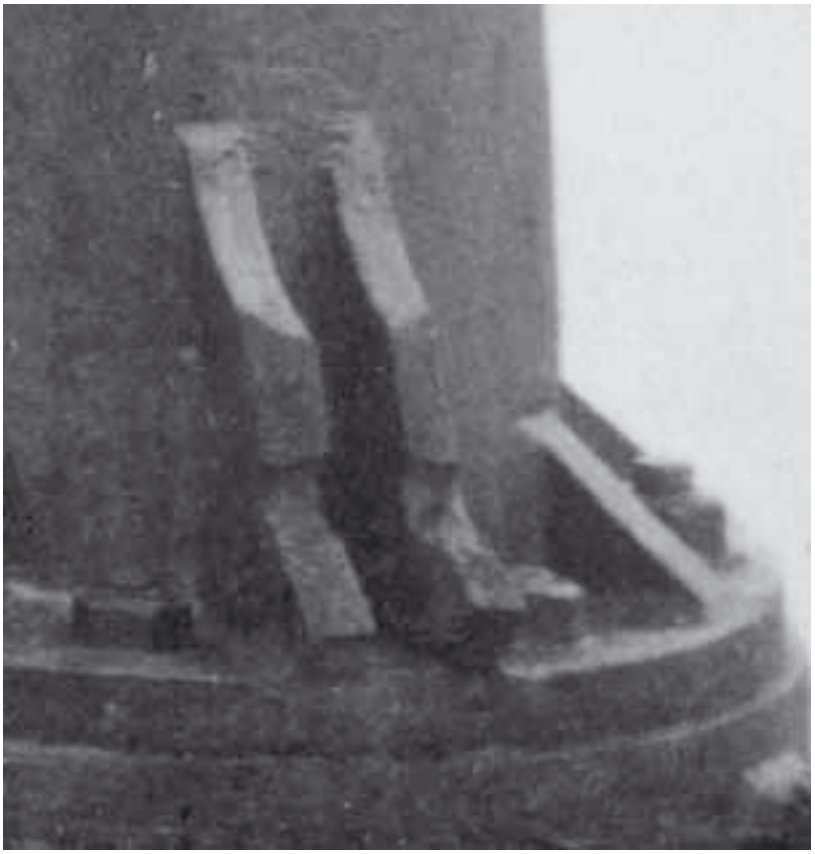

Figure C16 Fractured lug on pier 3

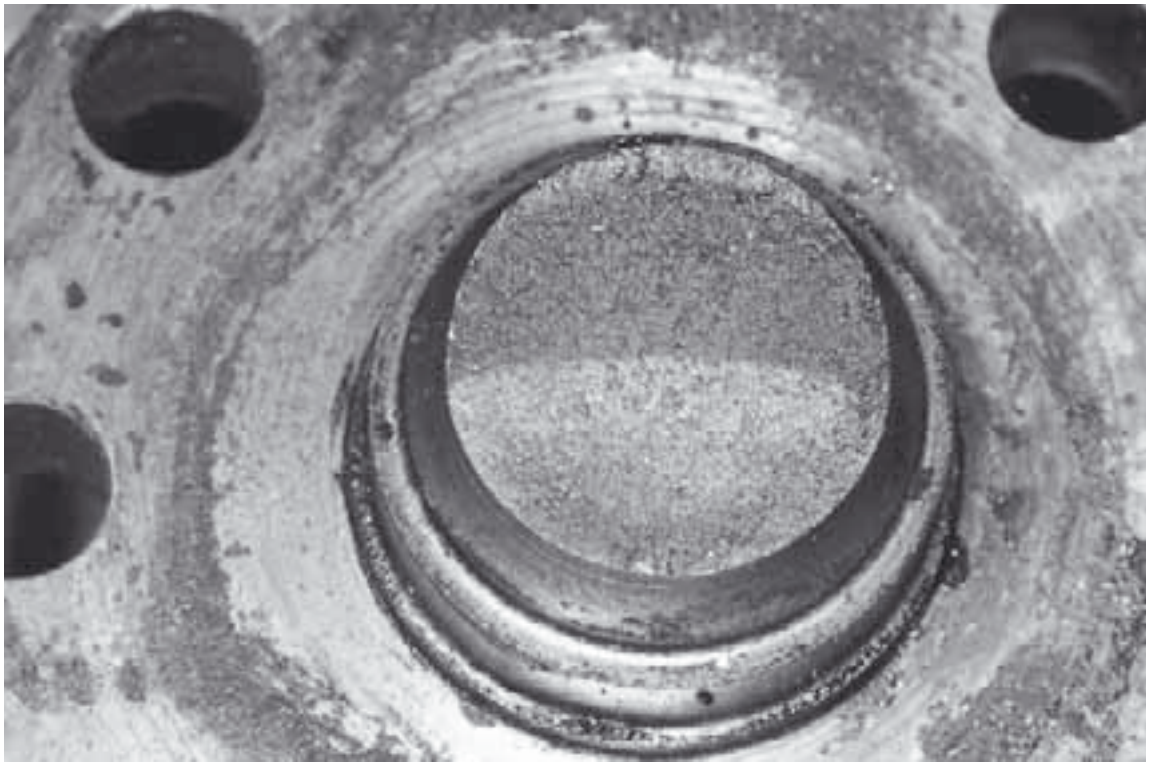

Figure C17 Brittle fracture in cast-iron